Terrain Travel Simulation: Data and Application

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Abstract

Research in visual representation of terrain supported the development of images for simulated travel. Results showed that observers can estimate distances in photographs, both from the camera station to a target and between targets; this performance is analogous to distance estimation in the real world. Distance estimation performance is affected by the focal length of the camera lens at which the picture is taken. Visual coherence (the appearance of travel) can be maintained when photographs are taken at steps greater than the ten feet used previously.

Introduction

Background

The Army travels and fights primarily on land; therefore, the ability to visually simulate travel over land is of critical importance in both the system development and training arenas. If terrain simulation were available, human-machine interface and training issues could be addressed both earlier and more frequently in the development of a system which is dependent upon visually guided behavior such as the ability to move or guide a system over land. In order to address these needs, the Army Research Institute (ARI), in cooperation with Decisions and Designs, Inc. (DDI), has developed an interactive visual display of terrain at eye-level under a project titled, Advanced Terrain Representation (ATR).

ATR is an interactive visual display which simulates travel over open terrain. Interactive connotes control by the user; simulated travel refers to the ability to travel visually; and "over open terrain" means that visual travel is not confined to roads but would allow the user the same mobility available to a tracked vehicle.

In earlier work (Lippman, 1980), still photographs were used to generate videodisc based surrogate travel. The user had control over CRT images which moved in response to the user's command which was transmitted to a microcomputer. The microcomputer sent a message to the laser reading the videodisc to "skip a groove" and to go to the appropriate picture. It is because of the videodisc's variable presentation capability (skips pictures) and the computer control, that the travel simulation was completely interactive.

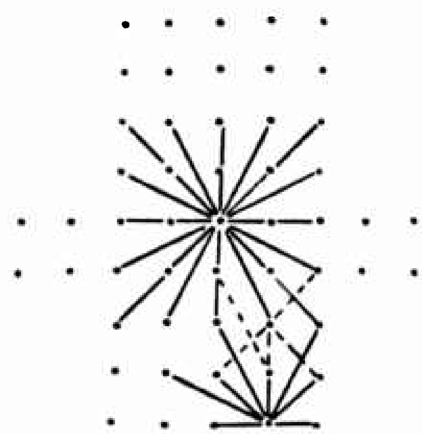
Lippman's surrogate travel constrained users to travel over streets; forward, backward, right and left. The objective of ATR was to extend this technology so that the system would emulate the ability of a tracked vehicle

to travel independently of roads, over open terrain. While the resulting visual travel is not as smooth as a moving picture, the effects of user control seem to be adequately compensatory.

Research Issues

The ATR project had two general objectives: the resolution of the logical problems involved in extending surrogate travel to a less restricted form of movement; and the determination of the optimal visual (spatial and temporal) resolution for producing an impression of motion.

The logical problems were resolved by utilizing a grid as shown in Figure 1. Each point on the grid represents a camera location. At each location, 16 photographs were taken with the direction of view being represented by the solid lines. Each direction of view is also a travel direction, and the broken lines show that travel can take place between any two adjacent points on the grid.



Computer control mandated that all photographs be taken with the camera on a level plane. Pilot research showed that visual travel up a hill was unrealistic under these circumstances if the hilltop was not in view. Increasing the camera lens angle provided the appropriate compensation but, at the same time, made objects in a scene appear more distant than they would appear if the focal length of the lens were set at "normal." The need to determine the effect of the camera lens angle (lens focal length) on the ability of humans to judge distances from observer to target and between two targets within a scene had critical implications for formatting the visual material to be used in this project.

Surrogate travel in Aspen was based on photographs taken at ten foot intervals. However, greater distances between photographs might still produce the desired visual coherence, the appearance of travel. If the photographs are too far apart, however, a viewer would become lost while traveling in a straight line because objects that should appear from scene to scene either change inappropriately or disappear altogether. The two experiments reported here were done to guide the development of ATR relative to the proper camera lens angle and the step size between pictures (visual coherence).

Experiment I

The perception of distance from the camera station to a target in a photograph can vary as a function of the lens angle at which the photograph was

taken. Camera lens angle, or angle of view (AOV), is a direct function of the lens focal length which ranges from telephoto (90mm, 30° AOV) to wide angle (35mm, 60° AOV). As the angle of view widens, objects appear smaller and farther away (Mascelli, 1965; Coynik, 1974; Giannetti, 1976).

There is a surfeit of psychological literature on how distance is perceived but very little information on real-world perception of distances over the range of interest to this particular project, from 10m to 1000m. The data which does exist (Gibson and Bergman, 1954; Gibson, Bergman, and Purdy, 1955; Teghtsoonian and Teghtsoonian, 1970) indicates that subjects increasingly understimate the distance to a target as that distance increases. When applying a power function to these data and those of Widen (1973a; 1973b), the exponents range from .67 to .86.

The purpose of this experiment was the determination of the viewing angle which most nearly induces the distance estimations produced in the real world. It was hypothesized that viewing angle would significantly affect the perceived distance tetween viewer and object in the manner specified by the aesthetic film literature. It was also hypothesized that the perceived distance between objects in the scene would remain unaffected by changes in viewing angle.

Method

Subjects. Twenty-four college students were paid five dollars an hour to serve as subjects. Subjects were run in five groups of two to six, and there were approximately equal numbers of males and females.

Stimuli and Apparatus. A total of forty standard 35mm color slides were taken: four apiece at ten locations. Four of the locations were in lightly wooded terrain, four in open terrain. At each of the ten locations, the four separate shots differed with respect only to focal length of the camera lens. The four focal lengths and the corresponding angles of view were as follows: 48mm, 48°; 28mm, 72°; 24mm, 84°; and 17mm, 104°. Each slide contained three naturally occurring target objects, one at each of three distances; near, mid, and far. For lightly wooded terrain, near was 0-50m, mid was 51-100m, far was 101-250m. For open terrain, near = 0-150m, mid = 151-450m, far = 451-1000m. The slides were arranged in four sets of ten with each of the ten locations represented once in each set. There was a practice set of two slides, and each set of slides was preceded by a title slide. The slides were projected onto a screen with a Kodak Carousel slide projector. Subjects were seated from 8 to 12 feet away and recorded their responses on a prepared data sheet.

Procedure and Design. Each subject viewed forty slides. While each slide was in view, the experimenter pointed out the target whose distance was to be judged by the subjects. Subjects were told to put themselves "in the scene as if taking the picture" and to judge the distance from themselves to the target. In addition, the slides of lightly wooded terrain contained objects separated by some distance that the subjects were to judge as well. A new slide was presented only after all subjects had responded to the previous slide. The slides were presented in one of four orders: 1, 2, 3, 4; 2, 3, 4, 1 etc. and all subjects responded to all slides. The design was a 2 (terrain) by 4 (viewing angle) within subjects design with three levels of object distance nested within terrain.

Results and Discussion

There was a highly significant effect of viewing angle for both lightly wooded terrain: [$F(3,69)=53.07$, $p < .0001$, MSe=2116.1]; and open terrain [$F(3,69)=11.37$, $p < .0001$, MSe=109,048]. As viewing angle widened, judgments of distance from observer to target increased accordingly. The results supported the notions of film theorists concerning the function of viewing angle.

The effect of differences in distances, i.e., near to far target, was also significant. For lightly wooded terrain, main effects were [$F(2,46)=104.51$, $p < .001$, MSe=16,130.5]; for open terrain [$F(2,46)=27.31$, $p < .0001$, MSe= 476,607]. The interaction between distance and viewing angle was also significant for both types of terrain, $p < .0001$ in both cases. Finally, there was no significant effect for order of presentation for either type of terrain.

Table 1 is a summary of the average judged means over three targets per picture compared to the actual mean for both types of terrain at each lens angle.

Table 1

Judged Distance for Terrain Type and Viewing Angle

Terrain	Viewing Angle			
	45°	72°	84°	104°
Lightly Wooded				
near (0-50m)				
mean judgment	17.06	26.95	29.92	38.77
mean actual	32.25	32.25	32.25	32.25
mid (51-100m)				
mean judgment	41.00	56.20	64.13	83.49
mean actual	69.50	69.50	69.50	69.50
far (101-250m)				
mean judgment	115.95	147.71	161.21	196.93
mean actual	184.50	185.50	184.50	184.50
Open Terrain				
near (0-150m)				
mean judgment	31.43	42.72	50.86	80.66
mean actual	48.00	48.00	48.00	48.00
mid (151-450m)				
mean judgment	105.05	147.97	163.56	254.43
mean actual	205.00	205.00	205.00	205.00
far (451-1000m)				
mean judgment	276.30	349.95	457.29	544.98
mean actual	6.3.75	613.75	613.75	613.75

When the Steven's power function was applied to these data, the exponents were .83, 45° viewing angle, .84 for 72° VA, .89 for 84° VA, and .79 for 104° VA. The exponents for distance judgments on actual terrain ranged from .67 to .86.

Human observers can judge distance in photographs in the same manner as they judge distances on real terrain. While viewing angle does have an effect, the range of exponents for photographs was more narrow than the range of exponents for actual terrain judgments. This is probably the result of having only subject and viewing angle variance. The actual distance estimations exponents were compiled across experiments and experimenters, as well.

72 to 84 degrees is the more desirable viewing angle, since the mean judgments were closer to the actual means while still being underestimations, a distinguishing characteristic of human performance on real terrain. The judgment of distances between target within the photograph was unaffected by the camera lens angle.

Experiment II

A terrain based travel simulation must be visually coherent if it is to have an applied or research value. Visual coherence means that what the user is seeing "sticks together" in some orderly way, the display makes travel sense to the user. In the case of ATR, visual coherence is a function of step size on the grid (distance between photographs) and directions of view and travel (number of photographs) at any grid point (see Figure 1). The results from the experiment on angular displacement are outside the scope of this paper, however, the minimum number of 16 directions of view were used in the demonstration.

Method

Subjects. Twenty-four university students were paid five dollars an hour to serve as subjects. Subjects were run in five groups of three to eight and there were equal numbers of males and females.

Stimuli and Apparatus. The stimuli were eight six-shot sequences of 35mm slides. The first four shots were taken at 10m increments. The distance between slides four and five ranged from 10-40m for lightly wooded terrain and from 15-75m for open terrain. Distance between shots five and six duplicated the distance between shots four and five. In addition, there were eight sequences with random displacements between shots four and five. The sixth shot in the random displacement sequence was systematically related to the fifth shot. There were also four practice sequences with feedback.

Two Kodak Carousel slide projectors were connected to a Model 2 Kodak Carousel dissolver in order to present the sequences with no blank time on the screen. The effect was a rough approximation of movement from slide to slide.

Procedure and Design. After seeing each sequence, all subjects used a special answer sheet with 10m hash marks to indicate their perception of type and amount of displacement between shots four and five, and then between shots five and six. There was also a "don't know" option if they saw no relation between shots four, five, or six.

Data were analyzed separately for terrain type with first and second displacement judgments analyzed separately and pooled. Since lightly wooded terrain and open terrain could be formatted differently within the final system, there was no need to pool data across terrain type.

Results and Discussion

Data were analysed on the basis of a frequency count of judgments for linear, random, or angular displacement. A chi-square analysis for lightly wooded terrain yielded a significant effect of displacement level, [$x^2(6)=36.4$, $p < .001$]. For open terrain, displacement distance was significant [$x^2(6)= 12.4$, $p < .05$].

In lightly wooded terrain, the perception of coherent travel began to fall apart at 30m displacements and became markedly worse at a 40m jump. Jump size in open terrain was coherent up to and including 35m. The 75m jump actually produced a greater number of responses indicating coherence than the 55m displacements, but this could well have been an artifact of the number of distinctive objects in the display. This number was not controlled by count in the creation of the stimuli.

Conclusions

The results of these two experiments have shown us that the parameters for developing a system such as ATR are wider than was initially assumed. ATR was implemented using 12m steps between grid centers. This creates a step of 27m on a diagonal and the conjunction of these step sizes may be disconcerting and require adjustment. However, the results which indicate that distance estimation where photographs are stimuli is analogous to distance estimation on real terrain leads us to believe that performance which requires distance, speed, and time-of-arrival estimations can be trained on ATR with reasonable assurance of training transfer. If this proves to be the case, then ATR can become a useful tool in the early evaluation of a system design relative to predicting human performance on that system.

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